Toward Model-Based Intent Detection for Lower-Extremity Exoskeletons

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I. INTRODUCTION

The US is home to more than a quarter-million individuals with Spinal Cord Injuries (SCIs) with 12,000 new cases each year and a cost of care exceeding $3 billion annually [1]. The application of robotic exoskeletons for gait rehabilitation following incomplete SCI has been steadily increasing, due in part to the repeatability of guiding the user's joints through normative trajectories.

Existing devices rely on relatively primitive methods such as joysticks and buttons for identifying the user's intentions to make changes to their gait. There is a need for more intuitive human-machine interface technologies to achieve increased fluency in this human-robot interaction (HRI). Across HRI more broadly, black-box strategies are conventionally employed for training and deploying intent recognition algorithms. By contrast, the central hypothesis of this work is that the fundamental mechanics of walking will enable model-based strategies to address the challenge of intent detection in the special case of lower-extremity assistive devices.

The model-based intent recognition strategy pursued relies on simplified models of human locomotion, also known as templates. The broad descriptive capabilities of existing template models (e.g., the Spring-Loaded Inverted Pendulum (SLIP)) suggest that estimation schemes based upon them will generalize well across users.

II. APPROACH

As an initial step, this work aims to estimate the target gait speed of an exoskeleton user by comparing exoskeleton sensor measurements to a library of gaits from the 3D Bipedal SLIP (B-SLIP) [2] model. Measurements are compared to multiple candidate gaits using an Interactive Multi-Model (IMM) filtering approach via a bank of parallel Kalman filters. These filters reconcile sensor measurements against the library of candidate gaits, and estimates from the filters are fused to form an ensemble estimate of the target gait speed.

Due to the hybrid nature of walking, B-SLIP gaits are further divided based upon gait events. A gait period is considered to start with the CoM loaded onto the trailing leg in single-support (SS1), proceed to the touchdown (TD) of the leading leg and enter the double support (DS) phase. The DS phase ends with lift-off (LO) of the trailing leg and the model enters the second single-support phase (SS2). The SS2 phase ends in midstance with the CoM over the leading leg.

Each phase of each gait is assigned as a dynamic model to the IMM filter bank. The IMM fuses estimates across all gait phases using a likelihood-based weighted average. In traditional IMM approaches, the likelihoods are based on measurement residuals and their covariances. As a key finding, this work has shown the importance and ability of also considering the physical likelihood of models based upon factors such as the presence of leg extension beyond the nominal leg length.

III. PRELIMINARY RESULTS

Preliminary results show that the IMM is successful in identifying the correct gait and gait phase. Results in Fig. 1 illustrate the likelihood of each gait phase rising and falling through a single step based on data generated by a B-SLIP model. With the addition of physical likelihood considerations in the IMM, likelihood changes coincide with the ground truth DS shown in grey. This algorithm is currently being extended to estimating the gait phase and target walking speed of a user walking in an exoskeleton with the help of crutches.

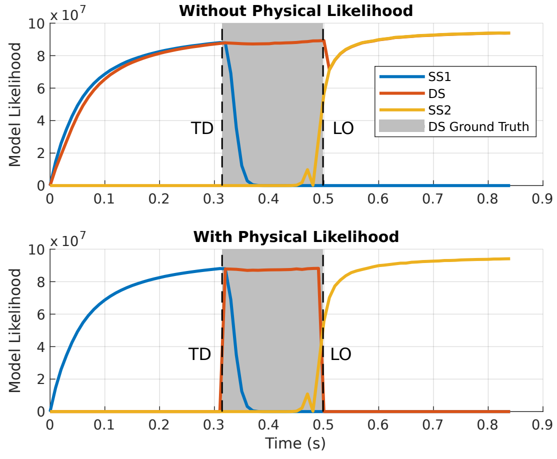

Fig. 1. Effects of including physical likelihood consideration within the IMM on the accuracy of gait phase detection.

REFERENCES

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